A Low-Cost ESP32 Node for Indicative Ethanol-Vapour Sensing, Engine Temperature Monitoring and GPS-Tagged Road Events: Prototype Design and Candid Assessment

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A B S T R A C T

Ethanol-blended petrol is now routine in India, and an engine control unit (ECU) that knows the blend in the tank can adjust fuelling, spark timing and cold-start behaviour to suit it. The factory flex-fuel sensors that supply this information are costly and tied to particular vehicles, which leaves students, small workshops and retrofit users with few options. This paper presents a compact prototype assembled from inexpensive modules around an ESP32. An MQ-6 metal-oxide sensor responds to fuel vapour, and its analogue output is averaged and scaled into a relative ethanol indication. The same board measures temperature with an NTC thermistor divider, reads two axes of a GY-273 (HMC5883L) magnetometer as a rough motion cue, and takes position, speed and time from a NEO-6M GPS receiver. A 16x2 LCD and the magnetometer share one I2C bus, and the readings go to a ThingSpeak channel every minute over Wi-Fi. The circuit was built on a hand-etched single-sided board and run on the bench. On the evidence collected, the unit shows temperature, ethanol indication and magnetometer values together on its display, and it logged eight data channels to the cloud between 17 and 19 October. The ethanol value is uncalibrated, the temperature and GPS channels have not been checked against reference instruments, and no test has been made on a running vehicle. A calibration plan and a route to a real ECU connection are outlined.

Keywords: flex-fuel sensing; ethanol vapour; MQ-6 sensor; ESP32; GPS-tagged road events; vehicle monitoring

1. Introduction

India has been raising the share of ethanol in petrol year after year. E20 is already sold at fuel stations, and higher blends such as E85 are expected to follow later (NITI Aayog, 2021). The same tank may therefore be filled with different mixtures on different days, and the engine notices the difference. Petrol burns cleanly at an air–fuel ratio near 14.7:1, whereas neat ethanol needs about 9:1. Ethanol's higher octane rating lets the ignition advance further, and its large heat of vaporisation makes cold starts more difficult (Tyagarajan et al., 2026; Azhaganathan & Bragadeshwaran, 2022). An ECU that is unaware of the blend can leave the engine lean, low on power and hotter than intended.

Production vehicles read the blend from a capacitive sensor in the fuel line. The sensor responds to the permittivity of the liquid and reports it as a frequency signal. Such sensors are accurate, but they are proprietary and were never meant for classroom experiments or retrofits. Ethanol is also volatile, and tin-dioxide sensors of the MQ family respond to alcohol vapour (Hanwei Electronics, n.d.). That points to a cheap route towards a blend indication, provided its weaknesses are understood and stated openly.

The prototype described here goes beyond a single reading. A node mounted on a vehicle is more useful when it also reports engine temperature and road condition, and when every observation carries a place, a speed and a time. We therefore put fuel-vapour sensing, thermistor thermometry, a magnetometer-based motion cue and GPS on one ESP32 board. The contributions are practical rather than production-grade: (i) a documented low-cost hardware and firmware

design that combines these four sensing functions with a local display and cloud upload; (ii) a clear separation between functions that were demonstrated, functions tested without a reference, and functions that exist only in code; and (iii) a concrete plan for calibrating the vapour channel and connecting the unit to an ECU.

2. Background and Related Work

Flex-fuel engine development for Indian conditions has been reported in the SAE literature, where the authors stress that injection and ignition adaptation depend on a dependable ethanol-content signal (Tyagarajan et al., 2026). A broad review of engine tests from E0 to E100 reaches the same conclusion: efficiency and emission benefits appear only when the control strategy follows the blend actually burned (Azhaganathan & Bragadeshwaran, 2022). Both works take the ethanol signal as given and do not ask how a low-cost device might supply it. National policy documents explain why varied blends will reach ordinary vehicles (NITI Aayog, 2021) but propose no sensing method.

MQ-series sensors use a heated tin-dioxide layer whose resistance falls when reducing gases such as alcohol vapour reach it (Hanwei Electronics, n.d.). The same data sheet presents the MQ-6 as a sensor for LPG-type gases, and the family is known for cross-sensitivity, drift, and dependence on temperature and humidity (Fraden, n.d.). Such sensors suit relative indication better than precise measurement. For temperature, an NTC thermistor with the beta-parameter model is a standard inexpensive choice, and the Steinhart–Hart relation is the more exact alternative (Steinhart & Hart, 1968).

Work on road-surface monitoring has used vehicle-mounted or phone accelerometers with threshold logic to flag potholes (Mohan et al., 2008; Eriksson et al., 2008). Some systems also stamp each detected event with a GPS position so that bad patches can be mapped (Eriksson et al., 2008; Mednis et al., 2011). Receivers of the NEO-6M class output NMEA text sentences at 1 Hz and quote roughly 2.5 m horizontal accuracy in open sky (u-blox, n.d.). To our knowledge, none of the literature we reviewed combines blend indication, engine temperature, road events and GPS tagging in one open, inexpensive design. This is the gap the prototype addresses. The vapour-based approach is accordingly treated as a low-cost indication method and not as a replacement for a production capacitive sensor.

3. Literature Survey

Table 1 lists the sources reviewed before the design was fixed, ordered from the latest to the oldest year of publication. Data sheets carry no publication year and come last. For each source, the table records what it contributed to this work and what it left unanswered.

Table 1 - Summary of the literature survey (latest to oldest; n.d. = no date).

Year	Reference	Key contribution	Limitation / gap
2026	Tyagarajan et al. (SAE Technical Paper)	Flex-fuel engine for the Indian market; injection and ignition vary with the ethanol fraction, so a dependable ethanol-content signal is needed.	Assumes such a signal exists; does not show how a low-cost device could provide it.
2022	Azhaganathan & Bragadeshwaran (Int. J. Energy Res.)	Review of E0–E100 engine tests; efficiency and emission gains appear only when the controller adapts to the actual blend.	Focuses on engine behaviour; little on measuring the blend in service.
2021	NITI Aayog (Roadmap for Ethanol Blending in India 2020-25)	National plan for higher ethanol blending; explains why vehicles will meet varied blends.	Policy document; offers no technical sensing solution.

Year	Reference	Key contribution	Limitation / gap
2011	Mednis et al. (IEEE DCOSS)	Pothole detection from smartphone accelerometers, with each event stamped by GPS position so potholes can be mapped.	Phone-based; no fuel or engine measurement.
2008	Mohan et al. (Nericell, ACM SenSys)	Detects potholes and bumps from sudden changes in motion-sensor output.	Relies on phone accelerometers; no fuel or engine monitoring.
2008	Eriksson et al. (Pothole Patrol, ACM MobiSys)	Vehicle-mounted sensors with threshold-based pothole detection, close to the threshold logic used here.	Needs a dedicated sensor network and accelerometers; more complex than one low-cost module.
1968	Steinhart & Hart (Deep-Sea Research)	Classical thermistor resistance–temperature relation; the simpler beta form is used here.	Accuracy depends on known constants; needs a check against a reference thermometer.
n.d.	u-blox NEO-6 data sheet	NMEA output at 9600 baud, 1 Hz default rate, about 2.5 m open-sky accuracy, start-up times.	Figures hold for good signal only; weaker indoors, in cabins and between buildings.
n.d.	Honeywell HMC5883L data sheet	Three-axis magnetic sensing over I2C, as used on the GY-273 board.	Senses magnetic field; does not measure acceleration directly.
n.d.	Espressif ESP32 data sheet	Dual-core controller with 12-bit ADC, I2C and Wi-Fi; ADC range limited to about 3.3 V and not perfectly linear.	General device document; nothing on fuel sensing or vehicle use.
n.d.	Hanwei MQ-6 data sheet	Tin-dioxide sensor for LPG-type gases with 5 V heater and analogue output; responds to alcohol vapour.	Cross-sensitive and drifting; gives vapour response, not blend; no conversion method.

The pattern is easy to see. The engine-side papers need a blend signal, the sensing papers do not deal with fuel, and the road-monitoring papers do not deal with the engine. The next section describes a design that brings these threads together.

4. System Design

4.1. System overview

The unit follows a simple sense, convert, decide and display routine (Fig. 1). The ESP32 reads the MQ-6 and the thermistor on two ADC1 pins, the magnetometer over I2C and the GPS receiver over a hardware serial port. The readings are converted to engineering values and passed through two decision rules, one for over-temperature and one for rough road. Results appear on a 16x2 LCD as three pages that rotate every three seconds, and once a minute the values are sent to ThingSpeak. ADC1 pins were chosen on purpose, because ADC2 channels cannot be used while the ESP32 radio is active.

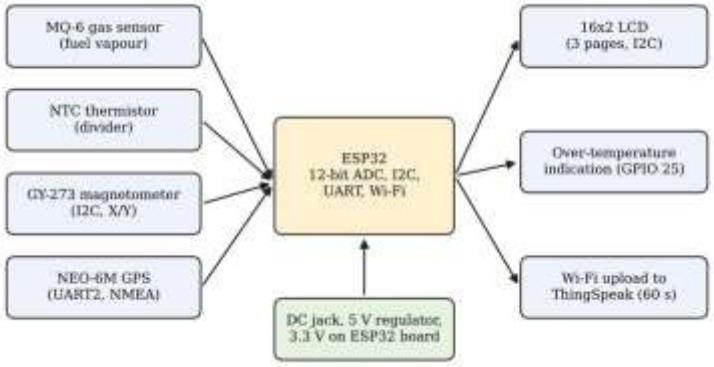


Fig. 1 - Block diagram of the prototype.

4.2. Hardware design

Table 2 lists the parts and the pins used. The board was etched on single-sided copper laminate. Power tracks were made wider, the short analogue tracks were kept away from the radio end of the ESP32 module, and capacitors were placed close to the regulator and the sensor supply. A DC barrel jack feeds a TO-220 linear regulator that provides the 5 V rail for the MQ-6 heater and the LCD, while the 3.3 V rail comes from the ESP32 board. The GPS board runs from 3.3 V and shares logic levels with the ESP32, so no level shifter is needed. The ground returns of the heater current and of the thermistor divider meet at a single point near the power jack, which keeps heater current out of the analogue ground path. The complete wiring is given in Fig. 2. Pins and rails that could not be confirmed on the assembled board are marked with ? or * in the drawing and should be read as proposed. The drawing also notes that the MQ-6 analogue output can approach 5 V and needs signal conditioning before it meets the 3.3 V ADC limit.

Table 2 - Main components and interfaces.

Part	Interface / pin
ESP32-WROOM-32 board	12-bit ADC, I2C, UART, Wi-Fi
MQ-6 module (SnO_2, 5 V heater)	Analogue output, GPIO 39 (ADC1)
10 kΩ NTC (B = 3950 K) + 10 kΩ resistor	Divider, GPIO 35 (ADC1)
GY-273 (HMC5883L), address 0x1E	I2C, SDA 21 / SCL 22
16x2 LCD with PCF8574 backpack, 0x27	I2C, shared bus
NEO-6M on GY-GPS6MV2 board	UART2, GPIO 16 (RX) / 17 (TX), 9600 baud
LED or buzzer	GPIO 25
Barrel jack, TO-220 5 V regulator, 3 electrolytic capacitors	5 V rail; 3.3 V from ESP32 board

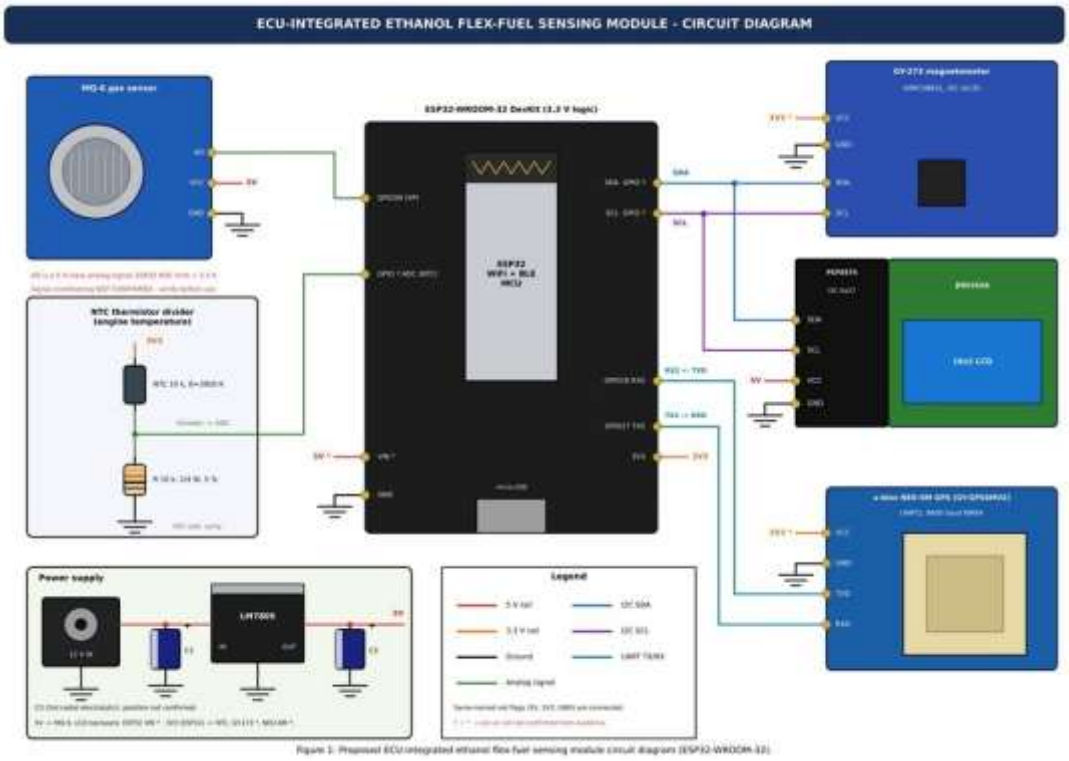


Fig. 2 - Circuit diagram of the proposed ECU-integrated flex-fuel sensing module (ESP32-WROOM-32).

4.3. Temperature measurement

The thermistor forms the lower leg of a divider across 3.3 V, with a fixed 10 kΩ resistor above it. From the measured divider voltage the firmware first finds the thermistor resistance and then the temperature, using the beta model:

$$R_t = R_{fixed} \times V_{out} / (V_{cc} - V_{out}) \quad (1)$$

$$1/T = 1/T_0 + (1/B) \times \ln(R_t / R_0) \quad (2)$$

Here T_0 is 298.15 K, R_0 is 10 kΩ and B is 3950 K. At 25 °C the divider sits at 1.65 V, the middle of the ADC range, where the converter is most linear. One ADC step is about 0.8 mV. That equals roughly 0.02 °C near 25 °C and about 0.1 °C near 90 °C, so converter resolution is not the limiting factor; the tolerances of the thermistor and the resistor are. Table 3 gives the design values that follow from these equations. The over-temperature indication switches on above 95 °C and off below 90 °C, and the five-degree hysteresis stops it from flickering. These limits are placeholders; they would have to come from the manual of the target vehicle.

Table 3 - Design values for the thermistor divider (computed, not measured).

Temp. (°C)	Resistance (Ω)	Divider voltage (V)	Expected ADC count
25	10000	1.650	2048
50	3588	0.871	1081
70	1760	0.494	613
90	934	0.282	350
100	698	0.215	267

4.4. Ethanol indication from fuel vapour

The MQ-6 reading rests on a simple observation. In a closed space above a liquid blend, the ethanol vapour content rises with the ethanol share of the liquid, so the sensor resistance falls and its output voltage rises. If temperature, chamber volume, sensor distance and waiting time are held fixed, the voltage-to-blend relation should repeat and could be stored as a calibration curve. Several caveats matter. The relation holds only under the conditions in which it was recorded, the sensor also responds to petrol hydrocarbons and other gases, and it needs several minutes of heater warm-up. The output is therefore a response to vapour and not a measurement of the liquid blend.

The baseline firmware that produced the logged data averages 20 ADC readings on GPIO 39 and applies a fixed empirical scaling:

$$raw = N_{avg} - 1530 \quad (raw = 0 \text{ if } raw < 40) \tag{3}$$

$$E\,(\%) = (raw / 2500) \times 98 \tag{4}$$

E is limited to the range 0 to 99.9 %. The offset of 1530 counts presumably represents the clean-air level of this particular module, and the constants were set from bench experience, not from reference blends. A second listing in our integration firmware uses a two-point model based on a clean-air voltage and a pure-ethanol vapour voltage. Metal-oxide response is non-linear, so the appropriate production approach is a multi-point look-up table built from laboratory samples, with temperature compensation. Neither the look-up table nor the compensation has been implemented yet.

4.5. Motion cue, GPS and event tagging

An accelerometer would be the natural road-shock sensor, but only a GY-273 module, which carries a three-axis magnetometer, was available to us. When the vehicle pitches or rolls over a bump, the sensor turns with it and the field components along X and Y change quickly. The firmware compares each X and Y reading with the previous one and sets a rough-road flag when either difference exceeds a threshold (6 field units in the integration listing). The flag is held for five cycles so that one rough patch counts as one event. Slow turns change the readings gradually and are ignored, but a sudden change of heading can still be mistaken for a bump, which makes this an indirect and imperfect cue.

The NEO-6M streams NMEA sentences once per second at 9600 baud. Each received character goes to the TinyGPS++ parser, and a position is accepted only if it is valid and no more than five seconds old; otherwise the display reads “GPS: no fix”. The serial receive buffer is enlarged to 1024 characters because the default of 256 would overflow during a long delay, and all waiting is done inside a function that keeps draining the port. When a new rough-road event starts, the firmware logs an event number together with the latest latitude, longitude, speed and UTC time, or records that no fix was available. With one fix per second, a vehicle at 60 km/h moves about 17 m between updates, so a tag points to a stretch of road roughly twenty metres long and not to the exact defect.

4.6. Timing, power and safety

One pass of the integration firmware takes about 0.7 s: roughly 0.2 s for averaging the analogue channels and 0.5 s for a wait during which the GPS is still serviced. That is ample for temperature and blend, which change slowly, but short road events can be missed. The estimated current draw is 0.3 A to 0.55 A, dominated by the MQ-6 heater, the backlight and the ESP32 radio. From a 12 V source, a linear regulator would dissipate about $(12 - 5) \times 0.45 \approx 3.2$ W. A heat sink or a switching converter is therefore recommended for in-vehicle use, and the regulator did become warm during bench tests. Petrol and ethanol vapour are flammable and the MQ-6 sensing layer is hot, so tests used small sealed samples in a ventilated place away from ignition sources. We would not place a bare heated sensor in a fuel tank or fuel line. A flame-arresting housing would be mandatory, together with a fuse and reverse-polarity protection on the supply.

5. Firmware Implementation

The firmware is written in the Arduino environment for the ESP32. At start-up it initialises the LCD, the I2C bus, the GPS serial port and the magnetometer, then waits out the MQ-6 warm-up while still feeding the GPS parser, so the receiver can begin acquiring satellites in the meantime. The main loop reads the three sensor groups, applies the temperature alert with hysteresis, checks for and tags a rough-road event, refreshes the current LCD page and prints a line on the serial port. Page 1 shows temperature and ethanol indication on the first line, and the X and Y values with a status character on the second. Page 2 shows latitude and longitude, and page 3 shows speed, satellites in use and HDOP. If the temperature reading falls outside the valid ADC range, which points to an open or shorted thermistor, the function returns not-a-number and the alert logic is skipped. A broken wire therefore cannot cause a false alarm or a false all-clear.
Telemetry uses an HTTP GET request to ThingSpeak every 60 s, after joining the local network with a 20 s timeout. The upload carries the field values, and the entry number returned by the server is checked to confirm success. For a later ECU link, the ethanol percentage, temperature and flags could be packed into the first bytes of a CAN frame, which is the usual way for a sensor node to report to a vehicle network. The position fields are intended for a phone or computer and not for the engine controller.

6. Results and Discussion

6.1. Local display

With no fuel sample near the sensor, the LCD showed 25.5 °C and 25.9 °C in two photographs of the same test, an ethanol indication of 0 %, and X and Y values that moved by less than one unit while the board sat at rest (Table 4). A room-temperature reading, zero in clean air and a quiet magnetometer at rest are what one would expect. A third photograph, shown in Fig. 3, showed 31.9 °C, an indication of 14 % and different X and Y values. The orientation of the board and the condition of the sample were not recorded for that photograph, so the observation is taken only as evidence that the sensor responds, not as a measure of accuracy.



Fig. 3 - Assembled hardware prototype in operation (reading 3 of Table 4). The MQ-6 module is connected by separate wires and lies outside the frame.

Table 4 - Readings taken from the prototype photographs.

Reading	Temperature (°C)	Ethanol shown (%)	X	Y
1	25.5	0	−11.7	37.8
2	25.9	0	−11.0	38.5
3	31.9	14	−28.4	−19.8

6.2. Cloud records

The unit uploaded eight channels to a ThingSpeak channel titled FLEX FUEL SENSOR at one-minute intervals: X, Y, ethanol indication, sensor voltage, latitude, longitude, speed and temperature. The X, Y, ethanol and temperature charts cover three groups of uploads between 17 and 19 October. The GPS charts show a window of about twelve minutes around noon with one point per minute, consistent with the upload interval. Values lie close together within each group and differ between groups. For X and Y this is plausible, because a magnetometer reads the Earth's field along its own axes and the board's orientation changed between sessions; orientation was not logged, however, so this is an explanation and not a result. Most ethanol values were zero. Non-zero values were about 11 on 17 October and between 8 and 14 on 19 October, and the voltage channel reached about 1.07 V. The maximum of 14 matches the value on the display. The temperature channel ranged from about 27 °C to 33.5 °C, in line with ambient conditions.

Two cautions apply. First, with no reference blend or calibration data, the non-zero ethanol values cannot be read as the ethanol content of any known fuel. Second, the plotted sensor voltage of about 1 V at an indication of 14 % does not agree with the baseline firmware, under which 14 % corresponds to roughly 0.29 V above baseline. The build that produced the logged charts therefore differed from the listing we keep as the baseline. We have left this discrepancy in the results and have not removed or adjusted it.

Fig. 4 reproduces the eight ThingSpeak field charts as recorded. The platform scales each chart automatically, several axes carry no units, and the lines joining separate groups of uploads span many hours without data. The shapes should therefore be read together with the axis values.

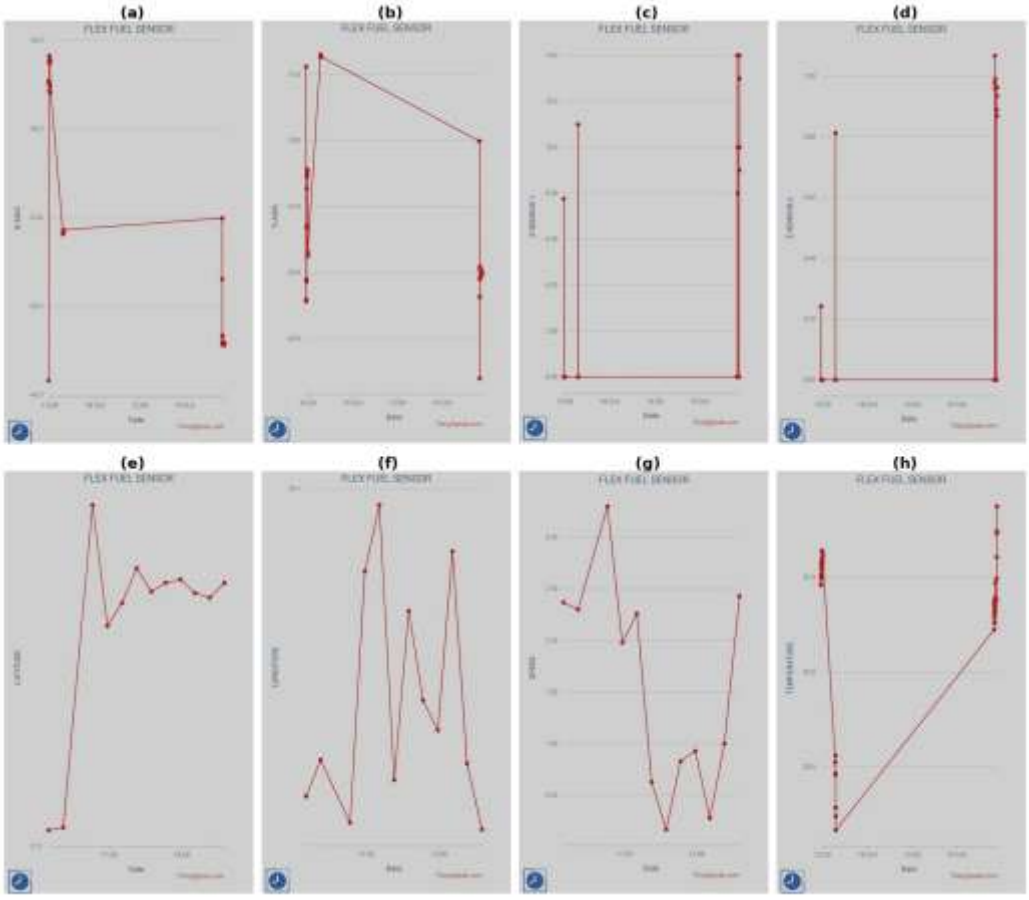


Fig. 4 - ThingSpeak field charts as recorded: (a) X-axis of the GY-273; (b) Y-axis of the GY-273; (c) ethanol indication (E-SENSOR 1); (d) ethanol sensor voltage (E-SENSOR.v); (e) latitude; (f) longitude; (g) speed from the GPS module; (h) temperature from the NTC thermistor.

6.3. GPS behaviour

Outdoors on the campus under open sky, the receiver obtained a fix in under a minute, tracked 6 to 9 satellites with HDOP between 1.2 and 1.8, and gave positions within roughly 3 to 5 m of a smartphone reading used as an informal benchmark. The position fell back to “GPS: no fix” indoors or with the antenna covered, while the other readings continued. The latitude and longitude of about 21.1° N, 79.1° E correspond to the Nagpur region. The speed channel ranged from about 0.2 to 3.3 km/h. Whether the unit was stationary during that window was not recorded, so this is best read as an indication of receiver noise at standstill and not as a speed verification. A comparison against a surveyed point and a reference speed source remains to be done.

6.4. Status of prototype functions

Table 5 summarises what the evidence supports. It separates functions that were demonstrated, functions that work but lack a reference measurement, and functions that exist only in firmware or as proposals.

Table 5 - Status of the prototype's functions.

Function	Status
Assembly on one board; LCD showing temperature, ethanol indication, X and Y	Demonstrated
Wi-Fi upload of eight channels to ThingSpeak at 60 s intervals	Demonstrated (logging build differs from baseline listing)
Thermistor temperature	Works; no reference-thermometer comparison
MQ-6 ethanol indication	Responds; no blend calibration
GPS latitude, longitude, speed	Works outdoors; informal comparison only
GY-273 readings	Demonstrated as readings; pothole detection not demonstrated
Over-temperature alert, rough-road flag, event tagging, three-page display	Implemented in firmware; awaiting bench validation
ECU link, capacitive cell, accelerometer, SD logging	Proposed

6.5. Comparison with a commercial sensor

A commercial capacitive sensor measures the permittivity of the liquid, reports the blend as a 50 to 150 Hz signal with fuel temperature carried in the pulse width, is accurate, and is largely unaffected by humidity and other gases. Our unit senses vapour, gives moderate accuracy that depends on calibration, is affected by humidity and other gases, and has no ECU output yet. Its advantages are low cost (the module parts cost roughly Rs. 1,500 to 2,400 at typical hobby prices), openness, and the added temperature, road and location information. The prototype is therefore better suited to laboratory learning and coarse blend indication than to direct replacement of a production sensor.

7. Limitations

The ethanol figure is influenced by temperature, humidity, other gases and the way the sample is presented. The sensor also drifts with age and needs a warm-up period, and a heated sensor is unsuitable for direct installation in a fuel line. Magnetometer-based pothole detection is indirect and can raise false alarms during quick heading changes. GPS gives no position indoors or in tunnels, a cold start can take half a minute or more, and the update rate limits location accuracy at road speeds. Most importantly, the unit has been tested only on the bench. Vibration, under-bonnet heat and electrical noise have not been examined, and neither has tagging at real driving speeds. The temperature table, the GPS comparison and the blend calibration table are still to be completed with reference instruments and certified fuels.

8. Conclusion and Future Work

This work built and bench-tested a low-cost ESP32 sensing node that shows an indicative ethanol reading, temperature and magnetometer values on a local display and uploads them, together with GPS position and speed, to a cloud channel. It confirms that such a device can be put together from inexpensive modules and that its parts communicate reliably over shared I2C, UART and Wi-Fi links. It also makes the limits of the vapour-sensing approach concrete.

The next steps, in order, are: calibration with sealed samples from E0 to E100 in a fixed chamber with temperature compensation; validation of the thermistor and GPS channels against reference instruments; demonstration of the alert and event-tagging logic; replacement of the magnetometer cue by an accelerometer; and a capacitive or optical cell for direct liquid measurement. A connection to a real ECU over CAN or UART can follow once the message format of a

target vehicle is available. A faster GPS update rate, SD or cloud logging of tagged events and long-duration vehicle trials would complete the move from bench prototype to field instrument.

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